Addressing the STEM challenge through targeted teaching: What's the evidence?

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Abstract

Numerous public reports are pointing to the critical importance of STEM (science, technology, engineering and mathematics) to Australia's future, but the number of students studying STEM subjects in senior years is declining, and many students in the primary and middle years of schooling do not have access to the ways of thinking and learning needed to succeed in school mathematics. Research over the past 10 years has established the critical role of multiplicative thinking in building student knowledge and confidence at this level of schooling, but there is a need for an expanded, evidence-based learning and teaching framework to support the development of mathematical reasoning more generally, if students are to have a realistic chance of actively participating in a STEM future.

This session will report on the findings and experience of an Australian Maths and Science Partnerships Programme (AMSPP) Priority Project in 2013 that explored the efficacy of formative assessment and targeted teaching in relation to multiplicative thinking in a number of secondary schools around Australia. It will also introduce the work of the Reframing Mathematical Futures II AMSPP project, which is aimed at building sustainable, evidence-based, integrated learning and teaching resources to support the development of mathematical reasoning in Years 7 to 10 in relation to algebra, geometry, statistics and probability.

Understanding the challenge: The role of multiplicative thinking

There are many reasons why Australian students choose not to pursue STEM-related studies in the senior secondary years, but a major contributing factor is the seven- to eight-year range in students' access to multiplicative thinking in the middle years of schooling, which is needed to solve more difficult problems involving rational numbers and proportional reasoning (Siemon, Breed, Dole, Izard & Virgona, 2006; Siemon, 2013a).

Multiplicative thinking involves recognising and working with relationships between quantities. Although some aspects of multiplicative thinking are available to young children, multiplicative thinking is substantially more complex than additive thinking and may take many years to achieve (Vergnaud, 1988; Lamon, 2007). This is because multiplicative thinking is concerned with processes such as replicating, shrinking, enlarging, and exponentiating, which are fundamentally more complex than the more obvious processes of aggregation and disaggregation associated with additive thinking and the use of whole numbers.

For the purposes of the Scaffolding Numeracy in the Middle Years Linkage Project (SNMY, 2003–2006), multiplicative thinking was viewed in terms of:

- a capacity to work flexibly and efficiently with an extended range of numbers (for example, larger whole numbers, decimals, common fractions, ratio, and per cent)
- an ability to recognise and solve a range of problems involving multiplication or division, including direct and indirect proportion
- the means to represent and communicate this effectively in a variety of ways (for example, words, diagrams, symbolic expressions, and written algorithms).

In short, multiplicative thinking is indicated by a capacity to work flexibly with the concepts, strategies and representations of multiplication (and division) as they occur in a wide range of contexts (Siemon, Breed & Virgona, 2005).

Project outcomes[1] included an evidence-based Learning and Assessment Framework for Multiplicative Thinking (LAF), two formative assessment options, and teaching advice specific to the eight developmental zones identified in the LAF. Medium to large effect sizes (in the range of 0.45 to 0.75 or more), as described by Cohen (1969), were found in research schools, compared to small to medium effect sizes (in the range of 0.2 to 0.5) found in the reference schools, suggesting that teaching that is targeted to identified student learning needs was effective in improving students' multiplicative thinking. Breed's (2011) 18-week intervention, conducted as part of the SNMY project, involved nine Year 6 students identified in Zone 1 of the LAF. When re-assessed three months after the intervention, all nine students shifted at least 4 zones, with the majority shifting five zones to be age- and grade-appropriate.

Targeted teaching

Conceptualised originally as assessment-guided instruction, this came to be referred to as *targeted teaching* in the latter part of the SNMY project (Siemon, Breed, Dole, Izard & Virgona, 2006). The value of using assessment data to inform and improve teaching, generally referred to as formative assessment, is widely recognised (for example, Ball, 1993; Black & Wiliam, 1998; Callingham & Griffin, 2000; Clark, 2001). However, it was felt that a different term was needed to distinguish the long-term, multi-faceted nature of the interventions needed to scaffold students' multiplicative thinking from the equally valid but short-term or spontaneous teaching decisions that might be informed by a pre-test on subtraction or an informal observation of student thinking in the course of a classroom discussion. Targeted teaching is characterised by an unrelenting focus on big ideas, where a 'big idea' for this purpose is an idea, strategy, or way of thinking about some key aspect of mathematics, without which students' progress in mathematics will be seriously impacted, that encompasses and connects many other ideas and strategies, and provides an organising structure or a frame of reference that supports further learning and generalisations. A big idea may not be clearly defined, but it can be observed in activity (Siemon, 2006).

Targeted teaching requires:

- assessment tools/techniques that expose students' thinking and provide valid and reliable information about where students are 'at' in relation to an important big idea
- a grounded knowledge of underlying learning progressions, key steps in the development and application of big ideas and how to scaffold these
- an interpretation of what different student responses might mean, and some practical ideas to address and progress student learning
- an expanded repertoire of teaching approaches that accommodate and nurture discourse, help uncover and explore students' ideas in constructive ways, and ensure all students can participate in and contribute to the enterprise

1 See: 'Scaffolding numeracy in the middle years', http://www.education.vic.gov.au/school/teachers/teachingresources/discipline/maths/assessment/Pages/scaffoldnum.aspx

- sufficient time with students to develop trust and supportive relationships
- flexibility to spend time with the students who need it most.

Importantly, targeted teaching is not a prescribed process; schools and teachers need to appropriate it to their circumstances and capabilities. Our experience to-date has shown this to be a very organic process that is not in any way equivalent to systematic streaming/tracking. It is best used where it has evolved over time with the support of key individuals and the leadership group. An example of this, Blue Sky College, is included in the recent Grattan report on targeted teaching (Goss, Hunter, Romanes & Parsonage, 2015).

Since 2006, the SNMY assessment options and teaching advice have been used in a range of coaching and professional learning activities in Victoria, South Australia, Tasmania and Queensland. However, while their use to support a targeted teaching approach has been generally successful in the upper years of primary school, their use in secondary schools has not been as widespread. Funding was obtained from the Australian Maths and Science Partnerships Programme (AMSPP) Priority Project round to explore the efficacy of and the issues involved in implementing a targeted teaching approach in secondary schools using the SNMY materials. Twenty-eight schools located in lower-socio-economic settings in the Northern Territory, Queensland, South Australia, Tasmania and Victoria participated in the 10-month study. Nominated 'specialists' in each school were provided with professional learning, and supported to work with at least two other teachers at their school to implement a targeted teaching approach to multiplicative thinking. The SNMY assessments were conducted in August and November of 2013. Matched data sets were obtained from 1732 students from Years 7 to 10, with the majority (59 per cent) from Year 8. Although the results varied considerably between schools, the overall achievement of students across the 28 schools grew above an adjusted effect size of 0.6, indicating a medium influence beyond what might be expected (Hattie, 2012). This can be seen in the shift in the relative proportions in each zone of the LAF from August to November, shown in Figure 1.

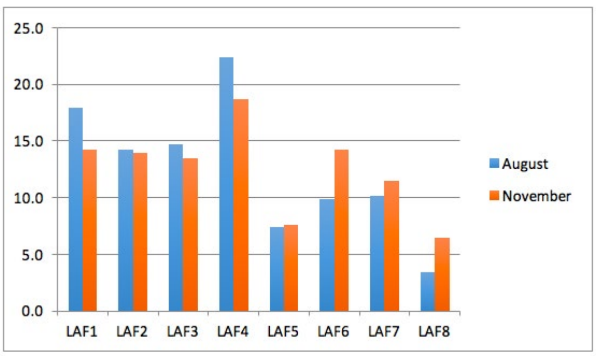

Figure 1 Proportion of students by LAF Zone in August and November 2013 (n=1732)

Mathematical reasoning

Mathematical reasoning – spatial reasoning in particular – is known to be associated with those engaging in STEM studies and STEM careers (Wai, Lubinski & Benbow, 2009). Described generally in the Australian Curriculum: Mathematics as a 'capacity for logical thought and actions', mathematical reasoning has a lot in common with mathematical problem-solving, but it also relates to students' capacity to see beyond the particular to generalise and represent structural relationships, which are key aspects of further study in mathematics and, thereby, STEM options.

Choosing and/or developing targeted interventions is difficult for teachers at all levels, but it is particularly challenging for those teaching out-of-field in the middle years who are faced with a seven- to eight-year range in student mathematics achievement. An integrated, research-based learning and teaching framework for mathematical reasoning is needed to inform a deeper, more connected approach to teaching all aspects of mathematics in Years 7 to 10. The framework needs to extend and add value to the LAF, recognise and build on what learners already know, and equip teachers with the knowledge, confidence and disposition to go beyond narrow, lock-step, skill-based, topic-focused approaches to teaching mathematics in the middle years.

Reframing Mathematical Futures (RMFII) is a three-and-a-half-year AMSPP Competitive Grant project that extends the Priority Project partnerships to include the Departments of Education in New South Wales and Western Australia and the Australian Association of Mathematics Teachers (AAMT). The aim of the project is to develop, trial and evaluate a learning and teaching resource to support algebraic, statistical and spatial reasoning in Years 7 to 10 that will enable teachers to identify and respond to student learning needs using a targeted teaching approach aimed at improving students' mathematical reasoning. For this purpose, mathematical reasoning is seen to encompass:

- core knowledge needed to recognise, interpret, represent and analyse algebraic, spatial, statistical and probabilistic situations and the relationships/connections between them
- an ability to apply that knowledge in unfamiliar situations to solve problems, generate and test conjectures, make and defend generalisations
- a capacity to communicate reasoning and solution strategies in multiple ways (that is, diagrammatically, symbolically, orally and in writing) (Siemon, 2013a, 2013b).

This is a non-trivial exercise that might be described as a Learning Assessment System (Masters, 2013). It requires the identification of Draft Learning Progressions (DLPs) for algebraic, spatial and statistical reasoning from existing research, the development and validation of rich tasks to assess and refine the DLPs using item response theory (for example, Bond & Fox, 2007), the preparation of targeted teaching advice, and the development and trial of a series of online professional learning modules. While there are elements to build on – for example, the LAF and Callingham and Watson's (2003, 2005) statistical literacy scales – this is a genuinely innovative endeavour that is reflected in the expertise of the research team, which, in addition to Rosemary Callingham and Jane Watson, includes Lorraine Day, Marj Horne, Rebecca Seah, Max Stephens, Bruce White and Tasos Barkatsas. Will Morony and Kate Manuel from AAMT are also members of the team. They are working with us and four other AMSPP projects to develop project materials for inclusion on a web-based professional learning portal.

The results of the SNMY project, the AMSPP Pilot Project and the preliminary analysis of the first phase of the RMFII project provides convincing evidence that targeted teaching works to improve student learning and engagement and teacher knowledge and confidence. We look forward to being able to report on progress in future forums.

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